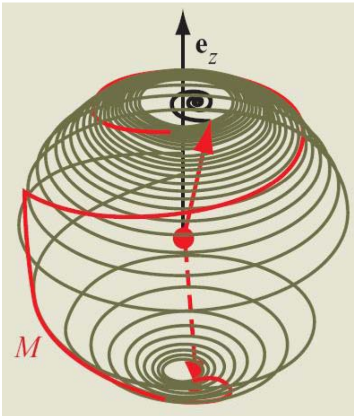
Current-sweep-rate dependence of spin-torque driven dynamics in magnetic nanopillars

Sebastian Dietze

Physics Department, University of Texas at Austin



Collaboration

- *University of Texas at Austin*

  Maxim Tsoi, Ph.D.

  Brian O’Gorman

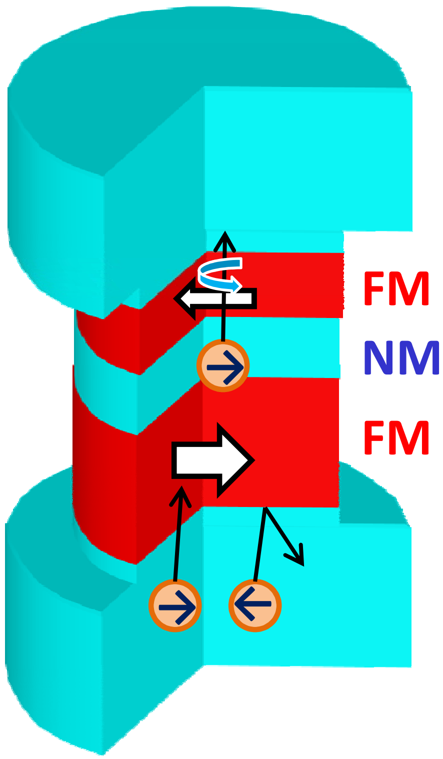
- *IBM's T. J. Watson Research Center*

  Jonathan Sun, Ph.D

Outline

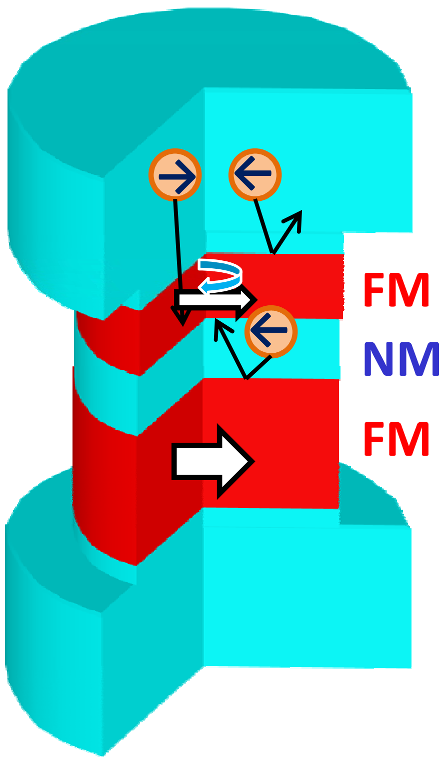
- Spin-Torque and Giant Magneto Resistance (GMR)
- Switching condition for spin-current-induced transitions
- Thermal-activation of spin-current-induced precessional state
- Conclusion

GMR and Spin-Torque



- Carriers with spin anti-parallel to the magnetic moment have a higher probability of scattering.
- When carriers scatter, interaction tends to align the spin of the carriers with the magnetic moment, which in turn delivers a spin-torque to the magnet.
- Thus, can use a large, fixed magnet to generate spin polarized current in order to manipulate a small, free magnet.

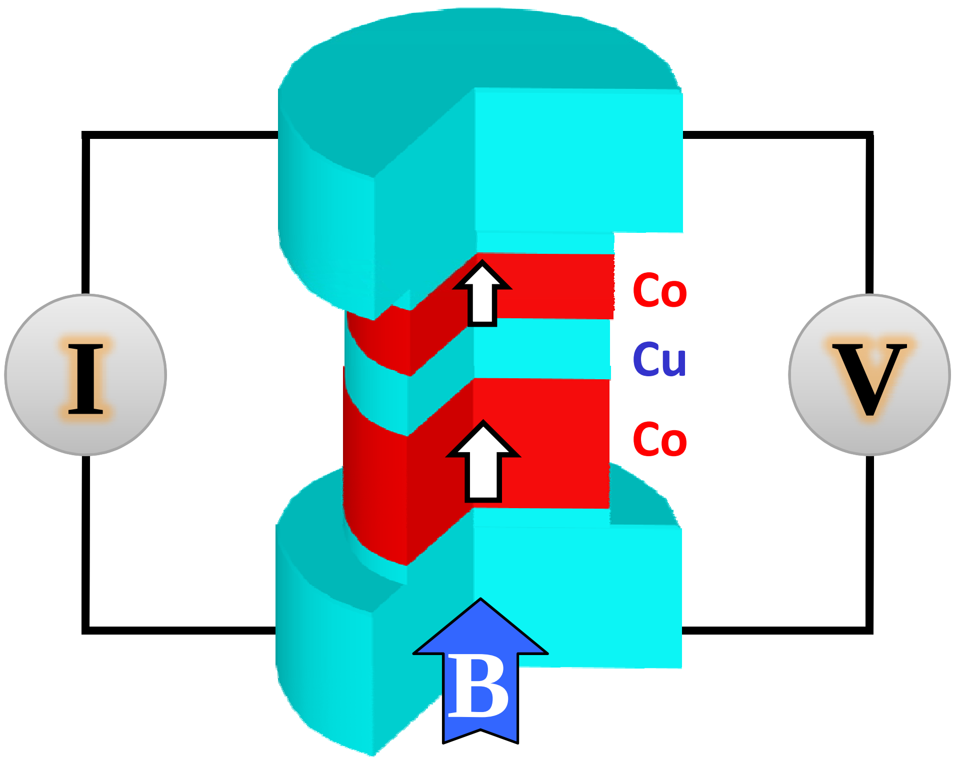
GMR and Spin-Torque



- The same can be done in reverse, via back scattering of anti-parallel spins. In conjunction of the original spins, this provides an equivalent strength spin-torque effect.

- Therefore, can manipulate a free magnet's orientation simply by applying a strong enough current in either direction.

Spin-Valves and Measurements



Elliptical spin-valve Co(3.7 nm)/ Cu(10 nm)/Co(12 nm) with lateral dimensions from 50 to 150 nm.

- Strong external perpendicular magnetic field brings moments out of plane for simpler dynamics

- Use 4-point probe to measure GMR. Thus, will know the relative orientation of the free and fixed magnets.

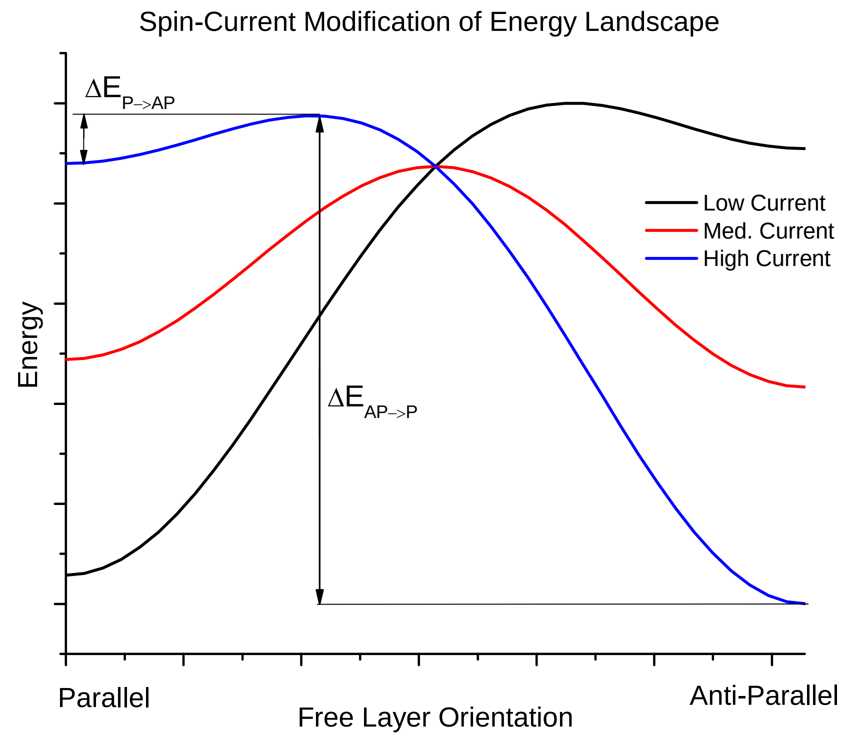
Energy Modification and Model

- Landau-Liftshitz-Gilbert (LLG) equation with Spin-Torque gives Spin-Current Modification of Energy Landscape

$$E(\theta) = -mB\cos\theta + \frac{\hbar}{2e}\frac{I}{\alpha\eta}\ln\{1+\eta\cos\theta\}$$

- This becomes a thermally activated process

$$\gamma = \gamma_\circ \exp\left\{\frac{-\Delta E}{k_B T}\right\}$$



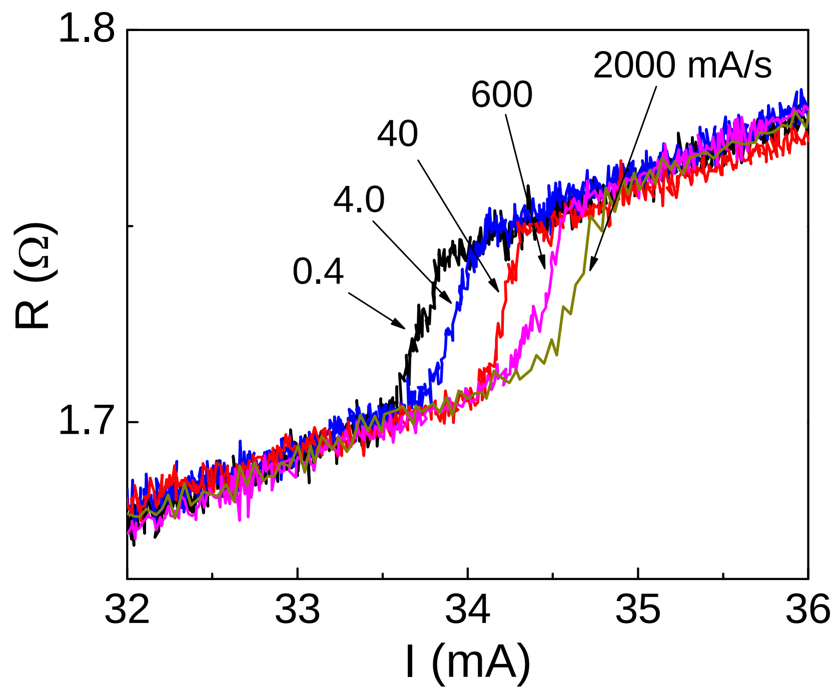
$$I_c = \frac{2e\alpha}{\hbar}\left((1+\tfrac{1}{2}\eta)mB + k_B T\left[\ln\left\{\frac{dI}{dt}\right\} + \ln\left\{\frac{\hbar}{4e\alpha k_B T\gamma_\circ}\right\}\right]\right)$$

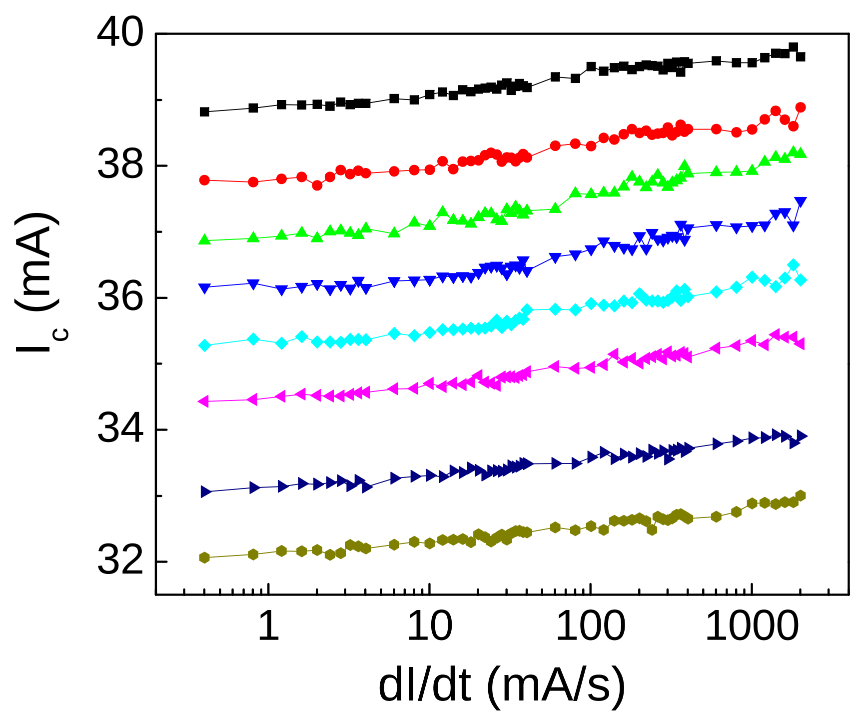
Z. Li et al., *Phys. Rev. B* **72**, 212411 (2005)

J. Z. Sun et al., *J. Magn. Magn. Mater.* **247** L237 (2002).

Sweeping Current

A higher sweep rate will result in less time for thermal activation. Thus, a higher current is reached before free magnet is switched.

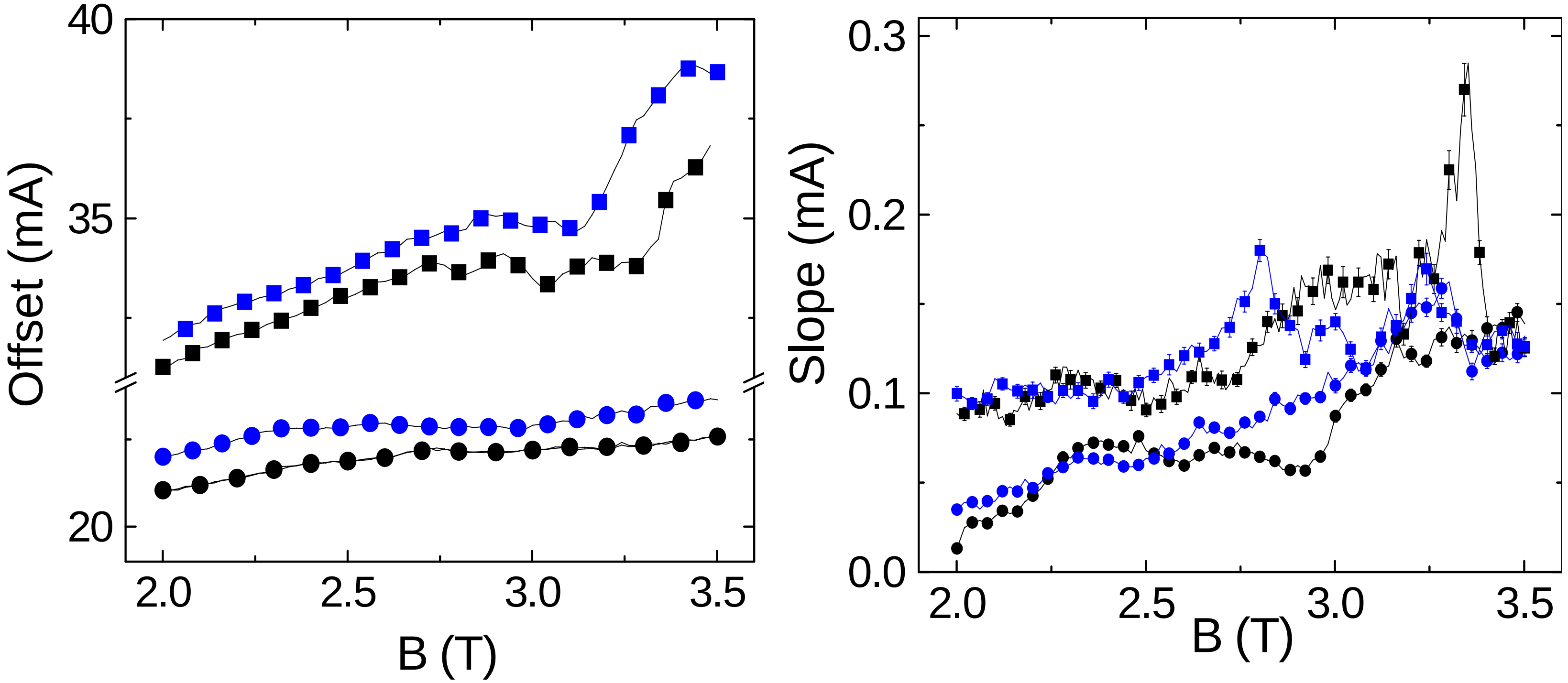




Bottom to top: 2.02, 2.28, 2.64, 3.16, 3.20, 3.24, 3.30 and 3.40 T

Field Dependence

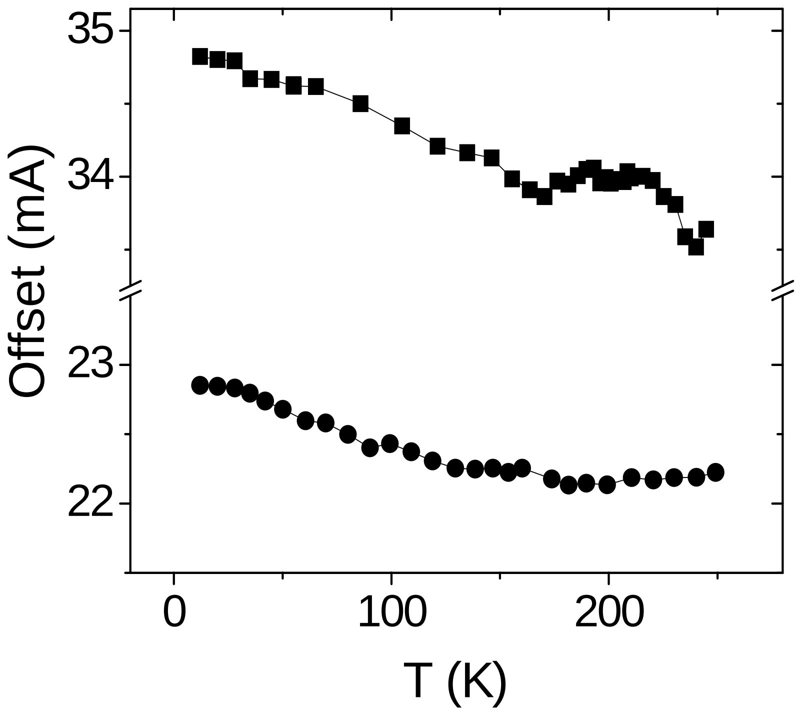
$$I_c = \frac{2e\alpha}{\hbar}\left(\left(1+\tfrac{1}{2}\eta\right)mB + k_B T\left[\ln\left\{\frac{dI}{dt}\right\} + \ln\left\{\frac{\hbar}{4e\alpha k_B T \gamma_\circ}\right\}\right]\right)$$

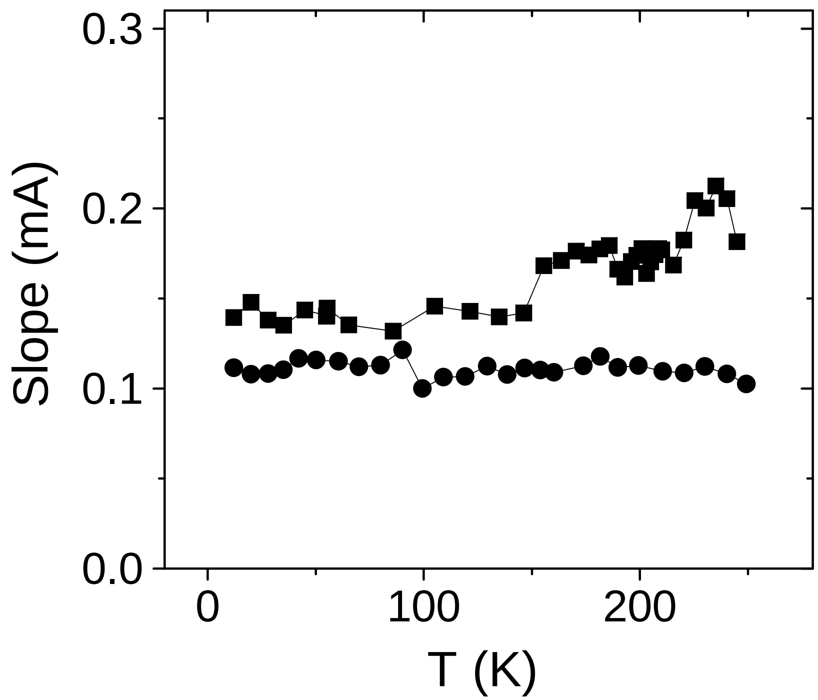


Here we show the field dependence of the offset (left) and slope (right) measured at room temperature (black) and 4.2 K (blue) of I_c vs. $Log_{10}\{dI/dt\}$, for the same two pillars. Note that the error bars are mostly smaller than symbol sizes.

Temperature Dependence

$$I_c = \frac{2e\alpha}{\hbar}\left(\left(1+\tfrac{1}{2}\eta\right)mB + k_B T\left[\ln\left\{\frac{dI}{dt}\right\} + \ln\left\{\frac{\hbar}{4e\alpha k_B T \gamma_\circ}\right\}\right]\right)$$





At temperatures between 4.2 and 300 K, we observe little to no dependence of the offsets (left). The observed slope (right) show a decreasing dependence on temperature. The squares (circles) show data for a 50×150 nm^2 (50×100 nm^2) nanopillar.

Conclusion

- Energy landscape is modified by Spin-Current to a regime where a thermal-activation occurs.
- Model has qualitative agreement in offset dependence on both applied field and temperature.
- Joule Heating cannot fully explain discrepancies
- Temperature dependence of parameters in Model could resolve failed prediction of slope behavior.

$$I_c = \frac{2e\alpha(T)}{\hbar}\left(\left(1+\tfrac{1}{2}\eta\right)mB + k_B T\left[\ln\left\{\frac{dI}{dt}\right\} + \ln\left\{\frac{\hbar}{4e\alpha(T)k_B T\gamma_\circ(T)}\right\}\right]\right)$$